**INDIANA DEPARTMENT OF TRANSPORTATION**
**MATERIALS & TESTS DIVISION**

# STRENGTH OF PORTLAND CEMENT CONCRETE PAVEMENT (PCCP) USING THE MATURITY METHOD UTILIZING THE TIME TEMERATURE FACTOR METHODOLOGY ITM 402-04T

## 1.0 SCOPE

**1.1** This test method covers the maturity concept as a non-destructive method to determine in-place concrete flexural strength in the field for opening of PCCP to traffic and during the verification of a new Concrete Mix Design (CMD).

**1.2** The values stated in either SI metric or acceptable English units are to be regarded separately as standard, as appropriate for a specification with which this ITM is used. Within the text, English units are shown in parenthesis. The values stated in each system may not be exact equivalents; therefore each system shall be used independently of the other, without combining values in any way.

**1.3** This ITM may involve hazardous materials, operations, and equipment. This ITM does not purport to address all of the safety problems associated with the ITMs use. The ITM user's responsibility is to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

## 2.0 REFERENCES

### 2.1 AASHTO STANDARDS

T 23, Making and Curing Concrete Test Specimens in the Field
T 97, Flexural Strength of Concrete
T 119, Slump of Hydraulic Cement Concrete
T 126, Making and Curing Concrete Test Specimens in the Laboratory
T 152, Air Content of Freshly Mixed Concrete by the Pressure Method
T 196, Air Content of Freshly Mixed Concrete by the Volumetric Method
M 241, Concrete Made by Volumetric Batching and Continuous Mixing

### 2.2 ASTM STANDARDS

C-1074 Estimating Concrete Strength by the Maturity Method

### 2.3 ITM STANDARDS

403, Water-Cementitious Ratio
802, Random Sampling
909, Verifying Thermometers

**3.0 Terms and Abbreviations.** Definitions for terms and abbreviations will be in accordance with 101, except as follows.

**3.1 Equivalent Age.** The time in days or hours at a specified temperature required to produce a flexural strength equal to the flexural strength achieved by a curing period at temperatures different from the specified temperature.

**3.2 Maturity Function.** A mathematical expression that uses the measured temperature history of a cementitious mixture during the curing period to calculate a maturity index that is indicative of the flexural strength at the end of that period.

**3.3 Maturity Index.** An indicator of flexural strength that is calculated from the temperature history of the cementitious mixture by using a maturity function.

**3.4 Maturity Method.** A technique for estimating concrete flexural strength that is based on the assumption that samples of a given concrete mixture attain equal flexural strengths if they attain equal maturity index values.

**3.5 Maturity Curve.** A curve established by plotting the flexural strength values vs time-temperature factor values.

**3.6 Maturity-Strength Relationship.** A relationship between the beam flexural strength and maturity index that is obtained by testing beam specimens whose temperature history up to the time of test has been recorded.

**3.7 Time-Temperature Factor (TTF).** TTF is a calculated value determined from time and temperature readings used to indicate the flexural strength of the concrete.

## 4.0 SIGNIFICANCE AND USE

**4.1** This ITM shall be used to determine in-place flexural strength of concrete for opening of PCCP to traffic.

**4.2** The hydration of cement and gain in strength of the concrete are dependent on both curing time and temperature. Thus, the strength of the concrete may be expressed as a function of time and temperature. This information may then be used to determine the strength of ~~concrete~~ PCCP without conducting destructive tests.

## 5.0 APPARATUS

**5.1 Beam molds:** Beam molds shall have the nominal dimensions of 150 mm x 150 mm x 500 mm (6 in. x 6 in. x 20 in.) in accordance with AASHTO T 23 and T 126.

**5.2 Flexural Strength Testing Machine:** A testing machine in accordance with AASHTO T 97 used to determine the flexural strength of concrete by breaking simply supported beams loaded at third points.

**5.3 Maturity Meter:** A device that automatically measures, computes and displays a time-temperature factor.

**5.4 Hand-held Digital Thermometer:** A verified thermometer having a temperature probe/sensor input connector and a power source. The minimum temperature measuring range shall be 0 °C to 66 °C. The thermometer shall be readable to 0.1 ° C and accurate to 1° C. Thermometers shall be verified in accordance with the applicable requirements of ITM 909.

**5.5 Temperature Probe/ Sensor:** Thermocouple, thermistor or other device suitable for embedment in the PCCP.

**5.6 Data Acquisition System:** A device suitable for monitoring and recording the temperature of the concrete. The device may be a system with a computer remote from the job site which reads and logs the probes/sensors through a modem for necessary calculations, or a system with a computer at the job site which automatically reads the probe/sensor signals, calculates the maturity index, and digitally displays the data on demand.

**5.7 Concrete Mixing Equipment:** The mixers shall be equipped with a metal plate or plates on which are plainly marked the gross volume of the unit in terms of mixed concrete, discharge speed, and the weight-calibrated constant of the machine in terms of a revolution counter or other output indicator in accordance with AASHTO M 241. The capacity of the concrete mixer shall be large enough to place twelve beams at one time and to conduct all other tests.

## 6.0 GENERAL

**6.1** This is a three step process.

**6.1.1** Laboratory procedure in accordance with 7.0.
**6.1.2** Field procedure in accordance with 8.0.
**6.1.3** Validation procedure in accordance with 9.0.

**6.2** An Excel based spread sheet computer program, MAT402, is furnished by the Department and shall be used to calculate TTF. The calculation is based on the following equation.

$$\sum TTF = \sum[\{(\frac{(T2 + T3)}{2}) + 10\} (A1 - A2)]$$

Where:

TTF, Time-Temperature Factor in °C x Hours
A1 - Age in hours
A2 - Previous age in hours
T2 - Concrete temperature in °C at measuring age
T3 - Previous temperature of concrete in °C

## 7.0 LABORATORY PROCEDURE

**7.1** Prior to construction a relationship between the TTF and the concrete flexural strength as measured by destructive methods through testing of beams shall be developed in the laboratory using project materials and the project CMD.

**7.2** Prepare concrete mixture and cast a minimum of twelve beams in accordance with AASHTO T 126. Tests for air content, slump and water-cementitious ratio shall be performed for each batch and recorded in accordance with AASHTO T 152, AASHTO T 119 and ITM 403 respectively.

**7.3** A temperature probe/sensor shall be inserted near each end of the last beam cast. The temperature/probe sensor shall be placed approximately mid-depth and approximately 75 mm (3 in.) from each end. This beam shall be designated the temperature control beam. This beam shall be the last beam tested for flexural strength. When a wired probe is used, secure the loose end wire of the probe/sensor to the beam box to prevent being inadvertently pulled out of the beam during first 24 h of curing.

**7.4** The beams shall be covered with wet burlap and polyethylene sheeting upon initial set. The forms, wet burlap and polyethylene sheeting shall be removed 24 h after casting. All beams shall be stored in a testing facility in accordance with 507.09, until each has been tested.

**7.5** The TTF and flexural strength at four different ages shall be determined and used in the development of the maturity curve. Additional ages may be tested. Three specimens, per age, shall be tested for flexural strength in accordance with AASHTO T 97. The TTF shall be recorded directly using a maturity meter or calculated from a temperature reading using a hand-held thermometer. The first three beams shall be tested for flexural strength 24 h after casting. The remaining tests shall be conducted at 12 h intervals and span a range in flexural strength that includes the desired flexural strength. An alternate testing schedule may be approved by the Engineer.

**7.5.1 Maturity Meter.** The Sum of TTF values are computed by the meter. The maturity meter shall remain connected to the temperature control beam until the last TTF is computed.

**7.5.1.1** One Sum of TTF, per probe, shall be entered in the Maturity Testing Curve Development sheet for the appropriate age. This sheet is found in MAT402, under tab labeled, Curve.

**7.5.2 Hand Held Thermometer.** The measured temperature shall be recorded and entered in the TTF worksheet for the appropriate age. This sheet is found in MAT402 under the tab labeled TTF calc. Temperatures for each probe shall be entered in a separate worksheet. The initial temperature of the first three beams shall be recorded at the time of casting. See ATTACHMENT I for a sample sheet.

**7.5.2.1** The Sum of TTF, for each probe, shall be entered in the Maturity Testing Curve Development Sheet of the appropriate age. This sheet is found in MAT402, under the tab labeled, Curve.

**7.6** Test the beams for flexural strength in accordance with AASHTO T 97. Record the actual load, average depth, and average width in the Maturity Testing-Curve Development Sheet, for the appropriate age. This sheet is found in MAT402 under the tab labeled, Curve.

**7.7** MAT402 shall be used to determine the maturity-strength relationship and to develop the maturity curve. The influence of maturity on flexural strength of concrete is CMD specific; therefore, a maturity-strength relationship and maturity curve established for one CMD shall not be used for another CMD.

**7.8** The computed $R^2$ value obtained from regression analysis of the maturity-strength relationship shall be 0.950 or higher. The $R^2$ value can be found on the maturity curve chart. When $R^2$ value is below 0.950, the TTF value will not be generated. Therefore the maturity curve is unacceptable.

**7.9** The TTF corresponding to the required flexural strength is calculated by MAT402 and is reported in the Maturity Testing-Curve Development Sheet. This TTF shall be used to determine when the PCCP has reached the required flexural strength. See ATTACHMENT II for a sample.

## 8.0 FIELD PROCEDURE

**8.1** Insert the temperature probe/sensor into the plastic concrete prior to curing.

**8.2** A minimum of two temperature probes/sensors shall be placed within 30 m (100 ft.) of the end of each production day or the last patch of the day. The Contractor may place additional temperature probes/sensors to substantiate required flexural strength at additional locations. The temperature probe/sensor shall not be placed within 1.5 m (5 ft) of transverse joint except for patching. The Engineer will determine the location of the temperature probe/sensor for patching. The tip of temperature probe/sensor shall be placed into the PCCP until the end is at approximately the pavement mid-depth and 0.5 m (1.6 ft) from the edge of the plastic PCCP. Insertion may be accomplished by attaching the tip of the temperature probe/sensor to a 6 mm (0.25 in.) diameter wooden dowel. The wooden dowel shall be removed.

**8.3** The data may be collected by a maturity meter or a hand-held thermometer. When a wired maturity meter is used, the temperature probe/sensor connector end shall be connected to a maturity meter in accordance with the manufacturer's instructions. When a hand-held thermometer is used, the temperature probe/sensor connector end is connected to the thermometer when a temperature is taken. The initial temperature of the PCCP shall be taken immediately after the temperature probe/sensor is inserted. The initial temperature of the concrete shall be recorded in the TTF Worksheet for each probe. See ATTACHMENT I for a sample of the TTF Worksheet.

**8.4** The PCCP may be opened to traffic when the average TTF of the two probes representing the end of the day's production reaches the required TTF as determined in accordance with 7.0. The average TTF at an additional location shall be calculated from the TTF of the additional probes at that location.

## 9.0 VALIDATION PROCEDURE

### 9.1 Field Validation Tests.

**9.1.1 Frequency of Validation Testing.** Validation testing is performed to determine if the concrete being produced is represented by the maturity curve for the CMD.

**9.1.1.1 QC/QA PCCP Pavements.** Validation tests shall be conducted on the third sublot of every fourth lot and on the first sublot of each new CMD in accordance with 501.04.

**9.1.1.2 PCCP Patching.** Validation tests shall be conducted on the first day of production and once every 600 cyds (500 m3) for each CMD.

**9.1.2** A minimum of three additional beams shall be cast in accordance with AASHTO T 23 at the time of the QC air content test for sublot.

**9.1.3** A temperature probe/sensor shall be inserted near each end of the test beam used to monitor temperature. This beam shall be designated the temperature control beam. The temperature probe/sensor shall be placed approximately mid-depth and approximately 75 mm (3 in.) from each end. Insertion may be accomplished by attaching the tip of the temperature probe/sensor to a 6 mm (0.25 in.) diameter wooden dowel. The concrete shall be consolidated around the dowel. When a wired probe/sensor is used secure the loose end wire of the probe/sensor to the beam box to prevent being inadvertently pulled out of the beam during first 24-h of curing. This beam shall be the last beam tested for flexural strength.

**9.1.4** The beams shall be covered with wet burlap and polyethylene sheeting upon initial set. The forms, wet burlap and polyethylene sheeting shall be removed 24 h after casting. All beams shall be cured in a testing facility in accordance with 507.09, until each has been tested.

**9.1.5** The TTF of the temperature control beam shall be monitored with a maturity meter in accordance with 7.5.1 or by temperature reading using a hand-held thermometer in accordance with 7.5.2. All three beams shall be tested when the control beam average TTF reaches or exceeds the expected value determined to represent the required flexural strength. The contractor's work schedule will determine time of testing. Report the TTF, the actual load, the depth, the width, and the age for each beam tested in the Maturity Testing-Curve Validation Sheet. This sheet is found in MAT402 under the tabs labeled, val.

**9.1.6** The average flexural strength of these three beams is calculated and compared to the predicted flexural strength by MAT402. This data is summarized in the Maturity Testing-Curve Validation Sheet. If the average of these tests is within 350 kPa (50 psi) of the original curve for the concrete mixture, the maturity curve is considered validated. If the average value is not within these limits, the maturity process is not valid. A computer printout example for validation of maturity curve is provided by ATTACHMENT III.

**10.0 REPORT** Copies of all computer printouts, diskettes and field data shall be submitted to the Engineer upon completion of the work. All thermocouple assemblies shall be cutoff flush with the surface of the PCCP upon completion of the work.

ATTACHMENT 1

ITM 402-04T

TTF WORKSHEET

Indiana Department of Transportation

## Maturity TestingTime Temperature Factor (TTF) Worksheet

Contractor: ABC CONSTRUCTION CO.

Project No.: R-99999 Probe No.:

Description: I-999 RECONSTRUCTION

Date: 10/22/98

Time: 3:00 PM

Datum Temp: - 10º C

| Reading | | | | | |
|---|---|---|---|---|---|
| Number | Date / Time | Temperature | Age | TTF (C°-hrs) | Sum of TTF (C°-hrs) |
| 1 | 5/5/98 8:00 A | 28 º C | | | |
| 2 | 5/6/98 8:00 A | 27 º C | 24.0 hrs. | 900.0 | 900.0 |
| 3 | 5/6/98 8:00 P | 26 º C | 36.0 hrs. | 438.0 | 1,338.0 |
| 4 | 5/7/98 8:00 A | 25 º C | 48.0 hrs. | 426.0 | 1,764.0 |
| 5 | 5/7/98 8:00 P | 20 º C | 60.0 hrs. | 390.0 | 2,154.0 |
| 6 | 5/8/98 8:00 A | 18 º C | 72.0 hrs. | 348.0 | 2,502.0 |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
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| 19 | | | | | |
| 22 | | | | | |
| 23 | | | | | |

Signature

*Contractor Representative*

# ATTACHMENT II

ITM402-04T

Indiana Department of Transportation

## MATURITY TESTING - CURVE DEVELOPMENT

Contractor: ABC CONSTRUCTION CO.

Contract No.: R-99999

Date: 05/05/99

Time: 1:48 PM

Location: I-999 RECONSTRUCTION

| Beam Number | Actual Load * (N) | Depth (mm) | Width (mm) | Flexural Coefficient | Flexural Strength (kPa) | Age at Break (hrs.) | Temperature-Time Factor | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Probe1 (C°-hrs) | Probe 2 (C°-hrs) | Average TTF (C°-hrs) |
| 1 | 24,500 | 152 | 152 | 0.1301 | 3,188 | 24 | 784 | 784 | 784 |
| 2 | 24,500 | 152 | 152 | 0.1301 | 3,188 | 24 | 784 | 784 | 784 |
| 3 | 24,500 | 152 | 152 | 0.1301 | 3,188 | 24 | 784 | 784 | 784 |
| 4 | 32,000 | 152 | 152 | 0.1301 | 4,164 | 36 | 1,566 | 1,591 | 1,579 |
| 5 | 32,500 | 152 | 152 | 0.1301 | 4,229 | 36 | 1,566 | 1,591 | 1,579 |
| 6 | 32,250 | 152 | 152 | 0.1301 | 4,197 | 36 | 1,566 | 1,591 | 1,579 |
| 7 | 35,600 | 152 | 152 | 0.1301 | 4,633 | 48 | 2,262 | 2,285 | 2,274 |
| 8 | 35,000 | 152 | 152 | 0.1301 | 4,555 | 48 | 2,262 | 2,285 | 2,274 |
| 9 | 35,000 | 154 | 152 | 0.1268 | 4,437 | 48 | 2,262 | 2,285 | 2,274 |
| 10 | 40,000 | 152 | 152 | 0.1301 | 5,205 | 60 | 2,858 | 2,852 | 2,855 |
| 11 | 40,500 | 152 | 150 | 0.1319 | 5,341 | 60 | 2,858 | 2,852 | 2,855 |
| 12 | 40,000 | 152 | 152 | 0.1301 | 5,205 | 60 | 2,858 | 2,852 | 2,855 |

### Plastic Test Results

Test No: P7
Air Content: 5.8%
Slump: 51 mm
W/C Ratio: 0.420

### Beam Monitoring

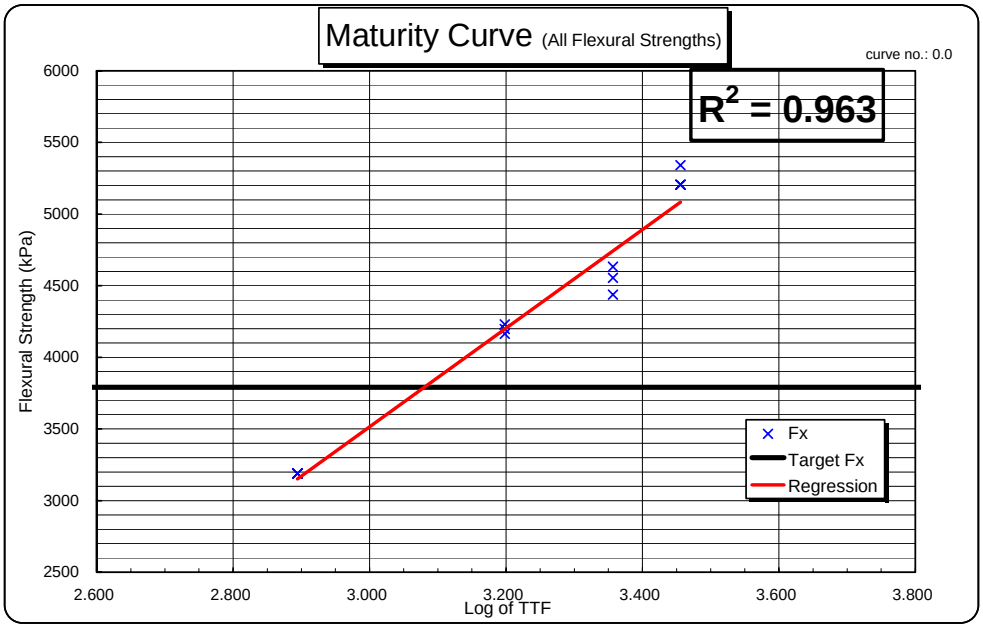
Equipment Used: Maturity meter

Starting Temperature: 20 ° C

### Maturity Criteria for Opening to Traffic

(Equivelant to 3792kPa flexural beam strength)

**TTF (C°-hrs)** 1,203
Log of TTF 3.080




Mix No.: 54648

### Mix Ingredients

| Material | Type | Manufacturer / Plant |
|---|---|---|
| Cement | Type 1 | Gray Bros. Industries |
| Fly Ash | Type C | Just Ash |
| Coarse Agg. | #8 Stone | Stone World / (3rd St. Plant) |
| Fine Agg. | #23 Sand | Just In Time Sand Co. / (Red River) |

| Admixture | Type | Source | Dosage |
|---|---|---|---|
| Water Reducer | SLS 5500 | XL Chemical | 14.00 mL/m³ |
| A. E. Agent | SOP2500 | XL Chemical | 14.00 mL/m³ |

Comments:

Signature

*Contractor Representative*

# VALIDATION

ITM 402-04

Indiana Department of Transportation

## MATURITY TESTING - CURVE VALIDATION

Contractor: ABC CONSTRUCTION CO.

Curve No.: **0**

Project No.: R-99999

Date: 05/10/99

Description: I-999 RECONSTRUCTION

Time: 8:09 AM

| Beam Number | Actual Load * (N) | Depth (mm) | Width (mm) | Flexural Coefficient | Flexural Strength (kPa) | Age at Break (hrs.) | Temperature-Time Factor: Probe 1 (C°-hrs) | Temperature-Time Factor: Probe2 (C°-hrs) | Temperature-Time Factor: Average TTF (C°-hrs) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 30,210 | 152 | 152 | 0.1301 | 3,931 | 36 | 1,275 | 1,275 | 1,275 |
| 2 | 30,200 | 152 | 152 | 0.1301 | 3,930 | 36 | 1,275 | 1,275 | 1,275 |
| 3 | 30,100 | 152 | 152 | 0.1301 | 3,917 | 36 | 1,275 | 1,275 | 1,275 |
| | | | | Average | 3,926 kPa | | | Average | 1275 |
| | | | | | | | | Log | 3.106 |

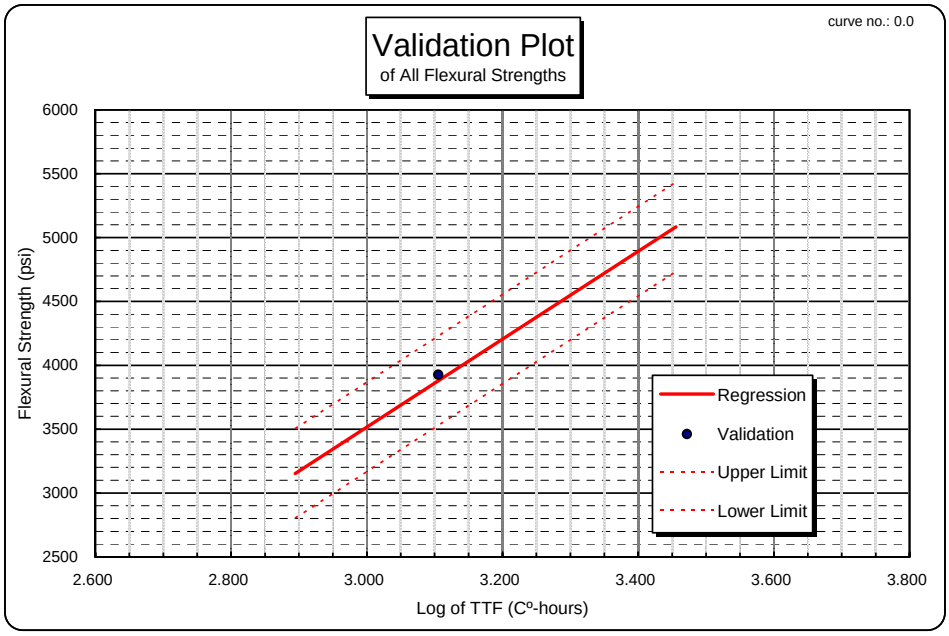
**Plastic Test Results**

Test No: P71
Air Content: 6.0%
Slump: 2 in.
W/C Ratio: 0.396

**Beam Monitoring**

Equipment Used: Digital thermometer

Starting Temperature: 22 ° C




| Summary | | | | |
|---|---|---|---|---|
| Predicted Beam Break* | | Actual Beam Breaks (average) | Difference from Target | Result |
| Lower Limit | 3,529 kPa | | | |
| Target | 3,879 kPa | 3,926 kPa | 47 kPa above | Within Acceptable Range |
| Upper Limit | 4,229 kPa | | | |

* Predicted beam break results were obtained by plotting the validation TTF on the mix maturity curve (above). Upper and lower limits are as specified for the test method.

Comments:

Signature

*Contractor Representative*